LUNAR ANORTHOSITE: IDENTIFICATION AND DISTRIBUTION OF REMNANTS OF THE PRIMORDIAL CRUST. C.A. Peterson[1], B.R. Hawke[1], P.G. Lucey[1], G.J. Taylor[1], D.T. Blewett[1], P.D. Spudis[2] [1]Hawaii Institute of Geophysics and Planetology, SOEST, University of Hawaii, Honolulu, HI 96822, [2]Lunar and Planetary Institute, Houston, TX 77058.

INTRODUCTION

Evidence strongly suggests that Earth's Moon was once covered by a magma ocean which differentiated as it cooled [e.g., 1]. In the later stages of crystallization, plagioclase feldspar formed a cumulate flotation crust composed primarily of anorthosite (rock containing >90% plagioclase feldspar) many kilometers thick. The concurrent and subsequent heavy bombardment experienced by the Moon has disrupted or obscured much of this original crust, but portions of it appear to have remained intact, especially on the northern lunar farside and globally at depth. While some other mechanisms for the production of anorthosite, such as the differentiation of plutons, have been suggested, the great majority of anorthosite outcrops present at the surface of the Moon today may be portions of the original crust.

Several spectral techniques are available for remotely identifying anorthosite on the Moon. They utilize multispectral data sets obtained from Earth-based telescopes or from spacecraft orbiting or flying by the Moon. While the techniques are related, they differ in their strengths and weaknesses. By comparing and combining the results from the various techniques we can increase our confidence in our understanding of the global distribution of anorthosite.

METHOD

Remote identification of lunar rock types using ground-based near-IR reflection spectra is relatively simple because of the small number of rock types which exist in significant quantity at the lunar surface and by the absence of water or atmosphere on the Moon which could alter the spectral appearance of the materials present there. The mafic minerals pyroxene and olivine can be identified by the presence of an absorption band near 1 µm [e.g., 2]. Plagioclase feldspar has no 1 µm absorption feature, but many highland rocks rich in plagioclase contain sufficient mafic minerals to exhibit an easily detectable band. Anorthosite contains no more than 10% mafic minerals, and lunar anorthosite is identified spectrally by the absence of any detectable 1 µm band. Because absorption bands in the spectra of lunar minerals become subdued over geologic time by the effects of micrometeorite bombardment and other space weathering phenomena, fresh craters provide the best opportunities for unequivocal identification of anorthosite using this technique.

Within the past several years, two spacecraft have returned multispectral image data sets for the Moon. Galileo made two passes by the Earth-Moon system on its way to Jupiter, and Clementine orbited the Moon for more than two months, obtaining near-global coverage. Both spacecraft collected data for five wavelengths in the UV to near-IR range [3,4]. The primary advantage provided by these data sets is their inclusion of data for the lunar far side, which can never be viewed directly from Earth. In addition, much of the Clementine data has better spatial resolution than does Earth-based data, and the near-global coverage by the same instrument allows for easier comparison of different areas on the Moon.

These data sets may be used in a variety of ways to search for anorthosite on the lunar surface. Band ratios are a simple but effective method for identifying anorthosite in fresh craters. Combining albedo and band depth information in a precise way can yield surprisingly accurate information on FeO content of most lunar materials. Full five point spectra may also prove to be valuable, but their utility will be greatly enhanced if ongoing efforts to accurately calibrate the Clementine near-IR camera data are successful and allow extension of the spectra into that region.

RESULTS

The simplest method for identifying anorthosite using Clementine or Galileo data is a comparison of albedo images and band ratio (e.g., 750 nm/950 nm) images. All fresh lunar craters are bright relative to their more mature surroundings. However, while freshly exposed materials with even modest amounts of mafic minerals exhibit significant 1 µm absorption bands and are therefore also bright in band ratio images, anorthosites, with no 1 µm absorption band, are much less bright. The craters Gassendi E and K, previously identified from ground-based spectra as exposing anorthosite, appear very bright in Clementine albedo images, but are nearly indistinguishable from their surroundings in the band ratio image.

By applying this relationship to the global Clementine data set it should be possible to quickly and easily identify fresh craters which expose pure anorthosite on any part of the Moon for which Clementine data is available. Such a search is planned, and results will be reported.

Lucey *et al.* have developed an algorithm which uses the same spectral data to determine the wt.% FeO of an imaged area [5]. The method has been recently refined by using individual Apollo landing site sample stations to improve the accuracy of the algorithm [6]. We have applied this technique to Clementine data for several anorthosite deposits on the lunar nearside which were previously identified from Earth-based near-IR reflection spectroscopy. The results in all cases show that the areas identified as anorthosite are dominated by material with no more than 2 wt.% FeO. Other regions in the same images show higher FeO values consistent with the rock types believed to be present at those locations.

Inspection of a global Clementine data set to which an earlier version of the Lucey FeO algorithm had been applied revealed that substantial portions of the farside, especially the north central region, were very low in iron. The region near the crater Fowler (43.1˚N, 145.0˚W) appeared especially low. Full resolution images in this region indicate that nearly the entire area is composed of material with less than 2 wt.% FeO, much of it less than 1 wt.%, clearly indicating that little but anorthosite can be present.

DISCUSSION

Analysis of data returned by the Galileo and Clementine spacecraft has greatly improved our understanding of the global distribution of lunar anorthosite. While some new anorthosite outcrops on the lunar nearside have been identified or confirmed with these data, the basic conclusions[7-10] derived from years of study of ground-based spectra have not changed. Anorthosite is not ubiquitous on or very near the surface of the lunar nearside. Large areas of the nearside are devoid of any detectable outcrops of anorthosite, and most anorthosites which have been identified are associated with basin rings, usually the inner rings. This suggests that the anorthosite was originally covered by a more mafic layer. After the basin-forming impact occurred, rebound brought the anorthosite to the surface or near enough to the surface to be exposed by subsequent smaller impacts.

The situation on the farside is quite different. Vast areas on the north central farside are composed almost entirely of anorthosite. It appears that the huge South Pole-Aitken basin is in large part responsible for the pattern we see on the farside today. The South Pole-Aitken basin-forming impact must have deposited enormous quantities of ejecta across much of the surface of the Moon. Near the rim of the basin, only very large basins, such as Orientale, could have completely penetrated the thick layer of ejecta from South Pole-Aitken. Further from the rim, smaller basins such as Birkhoff and Coulomb-Sarton (in the vicinity of Fowler) could easily have penetrated through the thinner deposits of South Pole-Aitken ejecta present there.

This simple scenario must be further investigated, but if it is confirmed it reinforces the contrast between the lunar nearside and farside. If we are to understand the big picture of lunar geologic history, we must have a clearer picture of how the crust has evolved. There are still large gaps in our understanding of the processes that shaped the lunar nearside, but the dominant role of South Pole-Aitken basin on the geologic history of the farside may greatly simplify the task of understanding the fate of a large portion of the original lunar crust.

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